USGS

WATER RESOURCES RESEARCH GRANT PROPOSAL

Title: High-rate anaerobic pretreatment of animal wastewater: Impact on traditional anaerobic animal waste treatment system performance and economics

Focus Categories: AG, TRT, WQL

Keywords: system engineering, anaerobic treatment, wastewater, animal waste, lagoons, benefit-cost analysis, anaerobic-filter, anaerobic sequencing batch reactor

Duration of Project: 3/1/99 to 8/31/00

Federal Funds Requested: $38,680

Non-Federal Matching Funds Committed: $78,800

Names and Affiliations of Principal Investigators: D. Raj Raman, Robert T. Burns

Congressional District: Second Congressional District of Tennessee

Statement of Critical Regional Water Problem

Due to the large volume of concentrated organic waste generated at modern animal production facilities, and the high cost of traditional wastewater treatment systems, land application of animal waste is the primary disposal method used by U.S. producers. Earthen lagoons are commonly used for storage of the waste and all associated flush water and storm water until land application. Throughout much of the United States, and especially in the warmer southern and island regions, these lagoons can function as anaerobic treatment systems and provide significant reductions in both the oxygen demand and nitrogen content of the wastewater. To achieve these benefits, lagoon organic loading rates must not be excessive or anaerobic treatment will be inhibited; large lagoon volumes have traditionally been used to provide non-inhibitory organic loading rates. However, many animal waste lagoons are overloaded organically, causing minimal (or partial) anaerobic treatment to occur. When waste from a poorly functioning lagoon is land-applied, the risk of surface and groundwater contamination increases because of its high organic content (such waste is also an odor nuisance). Protection of surface and groundwater is a Southern and Island Region priority; and the proposal addresses this priority through the development of an innovative wastewater treatment method for agriculture.

There are two distinct methods of reducing lagoon organic loadings: enlarge the lagoon or decrease the mass loading of organic matter through pretreatment. The goal of this work is to explore two promising pretreatment strategies in a series of lab-scale

experiments and to use standard engineering-economic principles to compare pretreatment methods with lagoon enlargement. The two pretreatment strategies of interest are both high-rate, retained-biomass anaerobic digestion processes: the anaerobic filter (AF) and the anaerobic sequencing batch reactor (ASBR). The ASBR is more complex, but will not require that solids be removed from the incoming waste stream; the AF is relatively simple, but will require that solids be removed from the influent waste stream to prevent plugging the unit. Although literature reports suggest that either of these technologies might work as pretreatment reactors, explicit comparisons of the two technologies on similar waste streams have not been conducted, nor have engineering-economic analyses. Both are necessary for the development and realistic evaluation of the technologies. If such work is carried out successfully, it will provide design engineers, regulators, and producers a much-needed tool for improving traditional animal waste management systems.

Research Results & Benefits

Primary Result: Determination of the feasibility of high-rate anaerobic pretreatment for animal waste lagoons, including kinetic studies and cost estimates.

Benefit: Offer a new, low-cost method of environmentally sound animal waste management. Most research on high-rate anaerobic processes for animal wastes have focussed on using the high-rate process as the primary treatment device. In contrast, we are examining the potential of relatively small (i.e., short retention time) devices as a method of enhancing the function of the lagoon, which will still function as the primary pollution-abatement and storage device.

Secondary Result: Develop reliable kinetic data on anaerobic filters and sequencing batch reactors treating dairy and swine waste in psychrophilic and mesophilic temperature ranges.

Benefit: There are no direct, long-term comparisons of different high-rate anaerobic processes treating the same waste, yet such data is critical to rational decision making. Where long-term temperature studies have been done, few have examined the cost issues raised by differences in operating temperature. The introduction of the results of this kinetic study into the literature will benefit researchers working on animal waste treatment and on other high-rate anaerobic systems.

Nature, Scope and Objectives of Research

Preamble: Anaerobic filters (AF) are continuous-flow fixed-film anaerobic digesters in which the majority of waste-degrading microorganisms are attached to a packing material inside the digester . Constraining the microbes in this manner leads to greatly increased waste treatment capacity and shock loading resistance. This technology is approximately 30 years old1, and several studies have shown that AFs operated at short-retention times can greatly reduce the organic content of animal wastewater. However, most

development work on the AF has involved high-strength industrial and food-processing wastewaters rather than animal waste

As their name implies, anaerobic sequencing batch reactors (ASBR) operate in a fill-react-settle-decant mode, and retain biomass through settling prior to the decant phase11. This technology is approximately a decade old , and as with the AF, treatment performance is enhanced through biomass retention. Several reports have examined the potential of ASBRs to treat animal waste.

Several investigations demonstrate the potential of AF and ASBR technologies to significantly reduce organic loadings in animal wastewaters3,4,5,13,14,15. However, none have explored the potential of using very short retention time systems for lagoon pretreatment, and no single study has made direct comparisons between the AF and ASBR. Furthermore, no economic analyses have been reported comparing the two technologies or examining the potential cost savings of combined high-rate and lagoon treatment.

Despite the similarities between AF and ASBR processes, two critical differences between them will influence their utility in agriculture. The ASBR is more technologically complicated than the AF, which implies increased costs (capital, operating and maintenance), and perhaps lower reliability. The AF is simpler, but solids can clog the packing media, making solids-separation a requirement for some animal wastes. Whether the complexity of the ASBR is offset by the cost of the AF has not been explored. By comparing the performance of both these reactors on identical waste streams, and with a very specific goal (the reduction of organic loading to a downstream lagoon), it will be possible to rationally choose between the two processes.

Nature of Research: The proposed study is a lab-scale investigation into the kinetics of organic matter removal in two types of high-rate anaerobic digesters. The reactors are relatively large by lab standards (ca. 25 L each), which greatly increases the likelihood that the results will be applicable at pilot- and full-scale. Augmenting the lab study are engineering-economic analyses to estimate the economic feasibility of using full-scale versions of these processes to enhance wastewater treatment in lagoons.

Scope of Research: Two regionally important animal wastes will be studied: swine and dairy. Both these wastes are frequently treated in lagoon systems. During the first year, the reactors will be designed, built, and brought on-line using dairy manure based wastewater. At the end of the first year, data will be available to evaluate the feasibility of the two reactor types for dairy applications. The second year will study swine waste treatment.

We will build and test two ASBR and two AF reactors, so that performance at 25 °C and 35 °C can be evaluated simultaneously.

During the kinetic experiments, data collection will focus on organic matter, characterized as chemical oxygen demand (COD), volatile solids (VS), and five-day

biochemical oxygen demand (BOD5). In addition, biogas production, biogas composition, volatile fatty acid (VFA) concentrations, and alkalinity will be monitored. These data will enable us to monitor and control the high-rate anaerobic processes to optimize their treatment performance.

The fundamental kinetic question can be stated as follows: How do changes in organic loading rate affect the organic removal rate and treatment efficiency of the reactors? Organic loading and removal rates are expressed in units of mass per unit reactor volume per unit time (e.g., typically kg m-3 d-1). Treatment efficiency is defined as the ratio of organic removal rate to organic loading rate. Choosing which parameter to use as a figure of merit depends on the goal of the system; often times the highest organic removal rate occurs at relatively low treatment efficiency, and vice-versa. (Note that in engineering design, the best figure of merit is neither organic removal rate nor treatment efficiency, but rather acceptable performance at minimum cost.)

Knowledge of system kinetics allows sizing of reactors. From an estimate of reactor volume, an estimate of reactor cost can be made based on commonly available price data. Thus, a well-executed kinetic study can form the basis of rational economic analyses of competing waste treatment technologies.

Anaerobic lagoon design is based in part on organic loading rate, with recommended maximum loadings of approximately 0.07 kg m-3 d-1in Tennessee (range in continental U.S. is 0.04 - 0.096 kg m-3 d-1). In contrast, lab-scale AF systems have been reported5 to achieve a 90% VS reduction in 2.1 d at an organic loading rate of 2.9 kg m-3 d-1. Similarly, recent reports on the ASBR for swine waste treatment14 recommend an organic loading rate of 4 kg m-3 d-1. Thus, high-rate systems are appropriately named, as they can handle 40 to 50 times the organic load that lagoons can. Their incorporation into agriculture will depend on true construction and operation costs though, not simply on organic loading rate, which is why it is critical to incorporate economic analyses into this project.

Objectives of Research:

A. Develop kinetic data for AF and ASBR systems operated at 25 °C and 35 °C treating dairy and swine wastewater. Specifically, measure organic removal rate as a function of organic loading rate, and thereby calculate treatment efficiency as a function of organic loading rate. Gather ancillary operating data while performing the kinetic tests, including biogas composition and production.

B. Use the data gathered in (A) to develop an engineering-economic model of high-rate anaerobic systems. Incorporate the model into a spreadsheet so that total system cost (the sum of the high-rate system plus the lagoon) can easily be computed for a variety of scenarios (e.g., varying land costs, liner costs, desired overall VS removal, desired VS loading to lagoon).

C. Use the results to design pilot scale reactors for use at cooperating farms (including experiment station units) to determine the applicability of these results to full-scale systems, and to refine the economic model.